STRAINED SEMICONDUCTOR MATERIALS, DEVICES AND METHODS THEREFORE

CROSS-REFERENCE TO RELATED APPLICATION AND PRIORITY INFORMATION

This application claims the benefit of U.S. Ser. No. 61/152,899 filed Feb. 16, 2009, which application is fully incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates generally to semiconductors, and more particularly to semiconductor devices involving strained semiconductor materials.

BACKGROUND OF THE INVENTION

A variety of electronic and optoelectronic fields and related devices use semiconductor materials to suit a variety of purposes. In many implementations, the properties of various materials used to make these devices are selected or otherwise tailored to suit specific applications.

One of many representative semiconductor fields that have been of significant interest in recent times is the field of optoelectronics. The field of optoelectronics includes those materials, structures, devices, circuits, and systems that have properties appropriate for facilitating optical-electrical energy and signal conversion, transmission, modulation, and detection. Most optoelectronic devices in production today use III-V materials to achieve high performance. However, in light of a number of drawbacks concerning III-Vs, including process/fabrication complexity, high material costs, and incompatibility with silicon (Si), among others, some researchers have begun exploring alternatives to these traditional approaches to optoelectronics problems.

Photodetectors, for example, are optoelectronic devices that convert optical signals into electrical signals. At a general level, a photodetector is at least partially comprised of a light-absorption medium that is in electrical contact with a set of electrodes. Light energy is absorbed in the medium by excitation of electrons from valence bands into conduction bands, while current is generated via the transport of these excited charge carriers to the electrodes and through an external circuit. In the case of light emission, light-emitting diodes (LEDs) and lasers are the optoelectronic counterparts to photodetectors, converting electrical energy into optical energy. At a general level, these light emitting devices are also at least partially comprised of an optically active medium, which may include a multiplicity of several materials with different characteristics, in electrical contact with sets of electrodes. In these types of devices, electrical energy is passed through the optical medium by the application of a potential difference via the electrodes. While current flows through the medium, some of the associated charge carriers recombine with each other as electrons drop from the conduction bands back to the valence bands. For radiative recombination events, the energy associated with these transitions is emitted in the form of light via photons. As a third category of optoelectronic devices, modulators modify light, converting electrical signals into optical signals. Generally, these types of devices are also at least partially comprised of an optically active medium, which may include a multiplicity of several materials with different characteristics, in electrical contact with sets of electrodes. The application of a potential difference across the optical medium via the electrodes changes its optical properties, modulating the properties of a beam of light passing through it.

Photodetectors, lasers, and modulators are some of the key components in optical communications systems and often operate at a wavelength range that is inclusive of about 1300 nm-1600 nm (i.e. they interact with light energy relatively efficiently at these wavelengths for these particular applications). For telecommunications, certain standards are defined around 1550 nm, where the 1528-1560 nm range is referred to as the "C-Band" and the 1561-1620 nm range is known as the "L-Band."

Many commercially available optoelectronic devices, such as the photodetectors, LEDs, lasers, and modulators described above, use type III-V materials such as GaAs, InGaAs, and GaN, which have the subset of disadvantages mentioned previously. For the particular examples here of photodetection, emission, and modulation, germanium (Ge) has attractive properties and is a promising silicon-compatible alternative as an optically active medium.

Unlike the III-V materials and their associated drawbacks, germanium does not undermine the performance of other devices that are built on a shared silicon-compatible platform. Therefore, silicon-compatible substrates can be used in a system that integrates other silicon-compatible electronic and/or optoelectronic devices and germanium-based optoelectronics, for example. Moreover, germanium fabrication and processing technologies are very similar to those used in traditional silicon manufacturing, reducing fabrication costs and complexity significantly compared to the III-Vs.

However, while bulk germanium may represent an attractive alternative to III-V materials for applications at the lower wavelength range, it suffers from limitations at wavelengths larger than about 1500 nm. In particular, bulk germanium has an absorption coefficient at 1550 nm that is about $\frac{1}{20}$th the absorption coefficients of some III-V materials (e.g. InGaAs), requiring a relatively thick germanium layer for comparable photodetection at this wavelength and resulting in low operating speeds. In terms of light emission, germanium's optical output is especially weak due to several competing phenomena. This less-than-optimal optoelectronic performance is directly related to the band structure of bulk germanium.

For the case of photodetection, when light is absorbed by a material, its energy is used to lift electrons above an energetic bandgap between the valence and conduction bands to higher-energy states. Thus, to first-order, if the incident light energy does not exceed the energy of the bandgap, the light cannot be absorbed and it passes through the medium undetected. In germanium, there are two particularly relevant bandgaps: the indirect L and the direct gamma. The indirect L bandgap is about 0.667 eV in energy, while the direct gamma bandgap represents an energy barrier of about 0.8 eV. In terms of light wavelength, these energies correspond to about 1860 nm and about 1550 nm, respectively.

Unfortunately, germanium cannot efficiently absorb light energy at the band edges for several reasons. Absorption leading to excitation above the indirect bandgap requires the co-action of a phonon-related momentum transfer along with the photon-related energy gain. The simultaneous occurrence of these two events at the right energy and momentum is relatively rare, resulting in small absorption coefficients for indirect gap transitions. For direct bandgap transitions at the germanium gamma point, the low density of available charge states near the conduction band edge limits the number of carriers that can be excited just above the direct gap. The density of such states increases beyond the band edge, but transitions to these states require higher-energy (smaller